DOMESTIC THERMOELECTRIC POWER GENERATOR

by

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14339

Dissertation submitted in partial fulfillment of
the requirements for the
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CERTIFICATION OF APPROVAL

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Approved:

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TRONOH, PERAK

September 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the reference and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

PUTERI NURFATIHAH BINTI HASIN@HASHIM

ABSTRACT

Due to being solid-state, maintenance free and noiseless, thermoelectric devices have found extensive applications in different areas since they were discovered over 180 years ago. The applications are concerned with power generation in industries utilities, transportation devices, medical service, space applications, military tools and environmental friendly refrigeration. The modules particularly attractive because it is utilize waste heat in varying applications. However, regardless of a few academic papers, there has not been extensive utilization in the domestic sector.

The concept of this thermoelectric generator is proposed to highlight on using waste heat from the environment and generate the electricity for domestic application. The prototype that will be developed in the laboratory is especially design to be implemented on all other area where the waste heat can be obtain such as from the stove, barbeque set, home heater and even heat from the solar radiation. The scope of this project is comprises of energy harvesting from the waste heat for power generation, power management and power consumption for high AC system.

The project is divided into two phase, the first phase is mainly on theoretical calculation for determining the number of TEG used for the system and identify the component require for power storage and conversion in order to supplying power to AC system. Experimental studies also will be carried out in order to identify the optimum power generation based on its temperature range and feasibility requirements. The collection of data compliment the second phase of the project which is the design process. During this phase, the design is develop from conceptual ideas into parametric design and finally fabrication process. The second phase of the project requires great consideration on various aspects such as product fabrication feasibility and materials.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBRIEVIATION

AC	Alternate Current
DC	Direct Current
TEG	Thermoelectric Generator
CHP	Combine Heat and Power
CTEG	Concentrated thermoelectric generator
PCM	Phase Change Material
KTEO	Kilotonne of oil equivalent

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, as the consequences of rapid growth in worldwide population and industrialization, there is a need to address some global issues which include air pollution and energy demand. The most favorable approach in contending the global warming is by designing a sustainable and green power system. Developing this power system also can reduce the electrical consumption by consumer since every year the electrical consumption has increase in Malaysia. Figure 1 shows the electricity consumption from 2003 to 2012 in Malaysia which is increased each year [1]. By inventing such device can reduce the electricity bill by the consumer, lessen the dependency on power grid and protecting the environment.

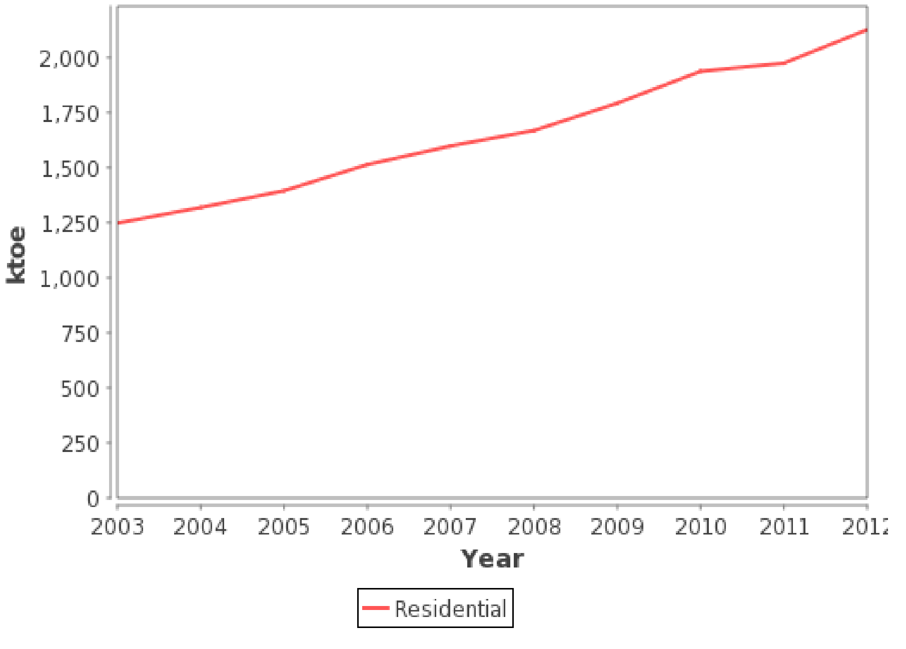

FIGURE 1. Electricity consumption in Malaysia

Most of energy from simple appliance to heavy equipment is wasted in the form of heat. In order to attain high efficiency, a lot of electrical machinery and electronic appliances have been enhanced, reutilized and recycled. Thus, to reuse them as renewable energy a new approach is needed. One such technology used is thermoelectric generator (TEG) which it is installed either within power plant station, automotive vehicle or even small electrical appliances. The simple working principle of TEG which is to convert heat energy from any extent of source including our body to acceptable electrical power has raised more studies and research in the recent years.

TEG present several distinct advantages over other technologies [2]. This is because it is an environmentally friendly device, reliable, less maintenance and since it not has mechanical moving part, so the operation is done in silent mode. TEG can be used at any time of day and any place because it is unlike wind turbine and solar panels which is depends on sunlight or wind. Besides, it is simple, compact, safe, very small size and virtually weightless. In addition, TEG does not need an auxiliary source of energy.

Thus, the purpose of this project is to applying the thermoelectric concept to utilize the waste heat from a common heat source in domestic environment such as solar radiation, stove, barbeque set and home heater to generate electricity. The benefit and potential of applying thermoelectric can be unveil by getting a superior understanding on the availabilities of these heat sources in domestic sector.

1.2 Problem Statement

From the observation on domestic sector, the energy loss or waste heat energy released by stove, barbeque set or home heater is wasted to environment and not being utilized. Developing a device that is able to harvest energy from waste heat can give a lot of benefits for mankind and save our environment.

Furthermore, the rising of electricity charges nowadays may give an adverse impact on consumer living cost. Thus, this project will provide alternative and supplemental electrical power for home owners as well as portable power so that it can reduce the electrical consumption from power grid. Therefore, the design of such device should be proposed to not only optimize the operation of the device, but also to hinder any drawback towards the performance of the applications. Design specifications such as mass, size, mountings and control system should be developed in such a way that it would not impose negative effects on the running in different source of heat.

1.3 Objectives

The main objectives of the proposed project are as follow:

1. To design a portable power for domestic application by utilizing heat energy.

2. To fabricate a portable power that can be used as a backup power source.

3. To investigate the performance of TEG in different source of heat energy and cooling system.

1.4 Scope of Study

The project comprises of three major components which are energy harvesting, power management and power consumption. The technique for energy harvesting is important for power generation. The heat from the environment or waste heat will be utilized by contacting it with the TEG that would convert the heat into electrical charges. The next step is to manage the power that produced from the TEG. This step is very crucial because the power that produced from TEG is small and not sufficient to power the electrical appliances. Therefore, power management will be compromise of power optimization, storage and conversion in order to be used in AC system.

The installed TEG itself is hoped to be able to recover the heat energy from the surrounding and provide additional electrical power to the electrical appliances such as lamp and fan in which would reduce the power load supplied by power grid. Thus, further studies should first be done on the heat energy resources form solar radiation and waste heat from home appliance that produce most heat loss. This is followed by investigation on the TEG itself in which the detailed product specifications should be verified beforehand especially in terms of its temperature limits and power generation capacity in order to properly converts those information into actual working design. Finally would be the development of the TEG itself which involve the product parametric structure, cooling system, the mounting on the specified location and the electrical distribution for home.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Existing Research on Thermoelectric Power Generator (TEG)

The idea of using thermoelectric power generator has been used by some researcher for domestic application as a standalone power source. Zheng et has proposed thermoelectric cogeneration system using the thermal energy from waste heat and solar radiation from boiler exhaust to generate electricity and produce preheated water by using the heat rejected from the cold side of TEG for home use [3]. The concept of domestic cogeneration system is shown in Figure 2. The challenging design of the project is to overcome the restrictions of heat transfer to thermoelectric module and eliminate from it.

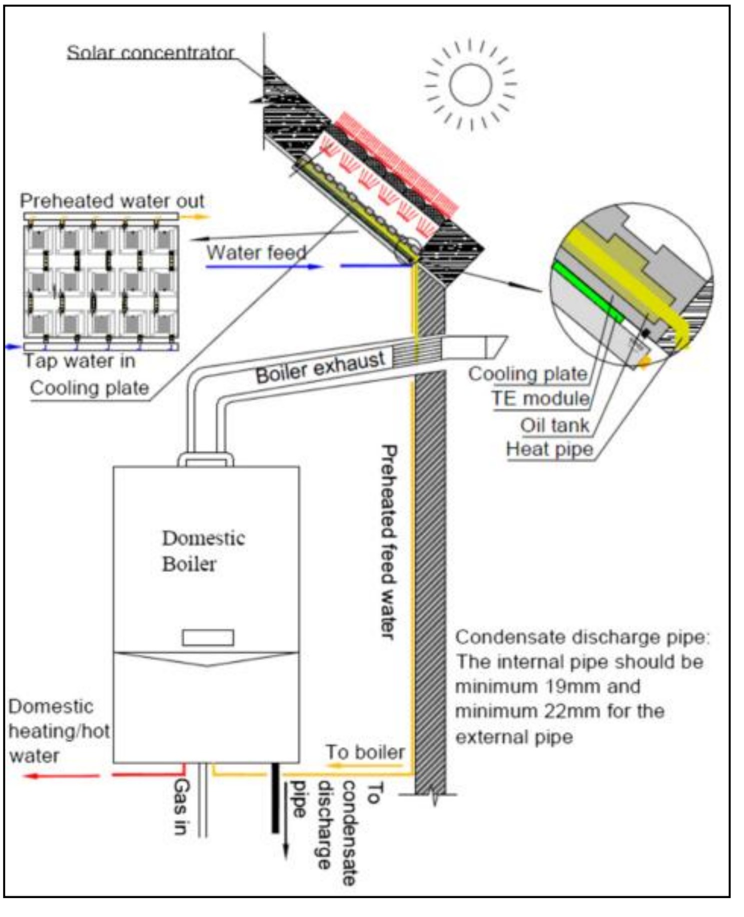

FIGURE 2. The concept of domestic thermoelectric cogeneration system

Apart from that, Yazawa has verified a theoretical model of solar concentrated combine heat and power (CHP) system by developing experimental equipment in order to produce hot water and generate electricity for domestic application. The concept of the system is shown in Figure 3. From the experiment, one thermoelectric module was produced power about 0.44-0.46W [4]. The main challenge is to optimize the apparatus thermally due to inconsistence profile of energy flux on thermoelectric module. Furthermore, Singh has performed a research on power generation from solar pond using combine thermoelectric modules and thermosyphon [5]. Thermoelectric modules are attached on thermosyphon where it is used to extract the trapped heat at the bottom of solar pond.

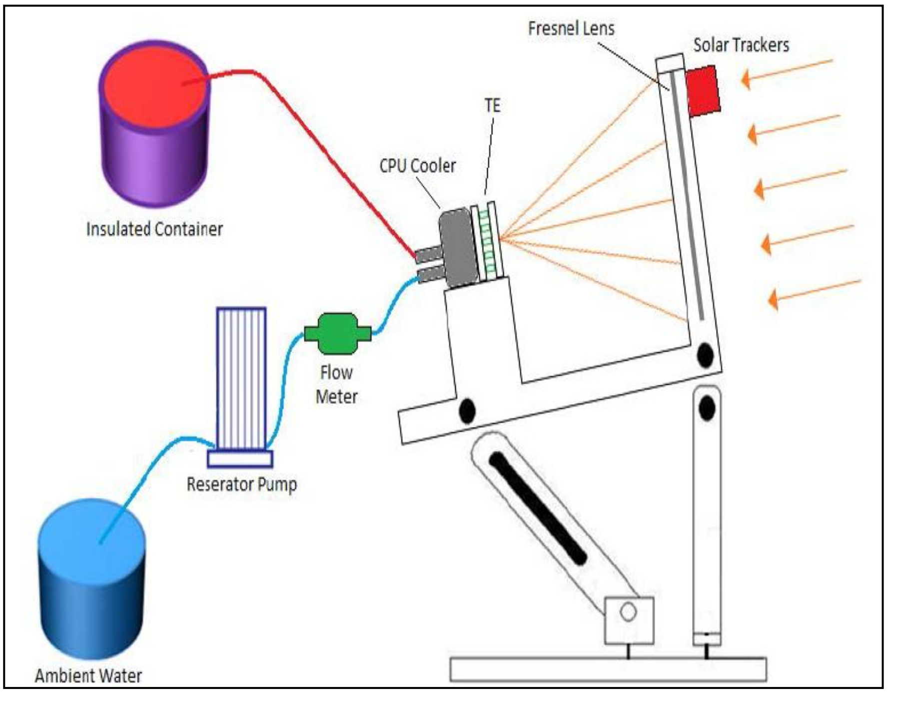

FIGURE 3. Theoretical model of CHP

In recent years, the viability of using solar radiation for thermoelectric generator has been explored by researchers as a sustainable heat source. Concentrated thermoelectric generator (CTEG) is a system uses concentrated solar energy as a renewable heat source in order to increase the temperature at the hot side of thermoelectric module. A model for CTEG system has been developed by Fan et al. by making a solar concentrator using parabolic dish collector in order to provide heat energy to thermoelectric module [6]. Maximum power of 5.9W is produced by using four pieces of bismuth telluride (Bi_2Te_3) with 68°C of temperature at the hot side and 35°C temperature difference. Tan et al. also has analyzed CTEG system numerically by using two phase close thermosyphon as heat transfer device from TEG to thermal storage [7]. The main challenge in the research is also the effectiveness in removing the heat at the cold side of thermoelectric module in order to achieve ideal temperature difference. Date et al. also proposed system consists of concentrated solar thermal device that provides a high heat flux source for thermal generators and it passively cooled using heat pipe that immersed in water tank [8]. The concept diagram is shown in Figure 4. Besides, Hasebe had applied the heat from road pavement as the effect of solar radiation in order to provide heat to the thermoelectric and for the cooling system they use river water to obtain temperature difference [9].

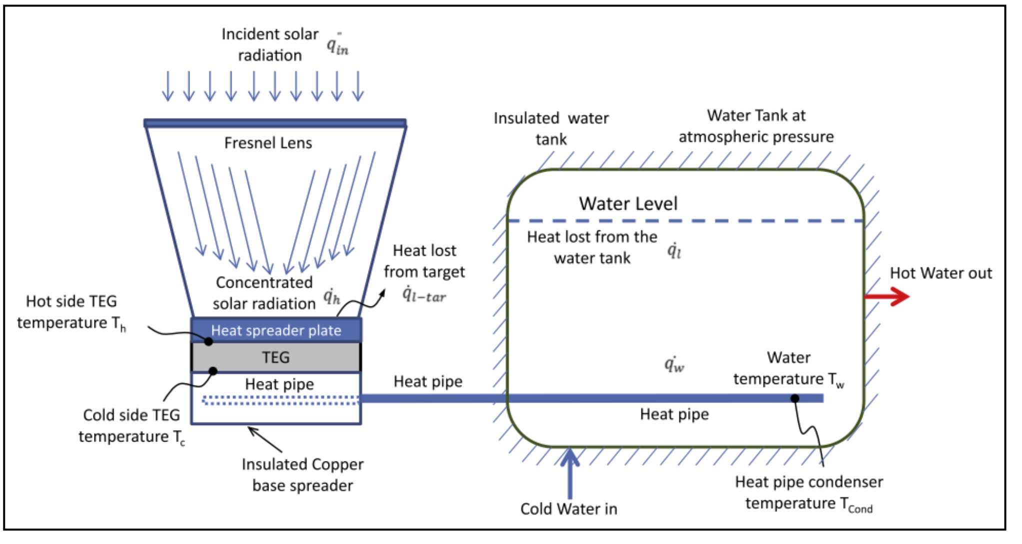

FIGURE 4. The concept of power generator using passive cooling

Beside of taking waste heat from solar heat energy, thermoelectric module also has being used by Champier [10] and Srivastava [11] to harvest energy from cooking stove in order to produce some electricity for domestic application in rural area. The specific design of TEG has been develop to make it suitable for use on the cooking stove. Apart from that, Alien [12] attempt to build up a self-power domestic boiler by integrating the thermoelectric modules between the combustion chamber and water conduit in the boiler enclosure. Qiu [13] has developed a thermoelectric generator system using the burning of natural gas in furnace to produce hot water and generate electricity. The operation is suitable for the applications which are purposely design for using the natural gas as primary fuel.

2.2 Thermoelectric Cooling Technique

The efficiency of removing waste heat at the cold part of thermoelectric module is important in order to attain an ideal temperature difference across TEC. Tan et al. has conducted an experiment on TEG by using solar concentrator and latent heat storage that act as cooling resources [14]. Paraffin wax which is a phase change material (PCM) is used to absorb the dissipated heat from the thermoelectric module.The concept diagram of CTEG with PCM is shown in Figure 5. The result shows that by using two small TEC, the system is capable to produce about 4W of power. Meanwhile, Yazawa has used a commercial water flowing CPU cooler on the cold part of TEC to extract the heat [4]. The heat will be absorbed by the water that flow through CPU cooler and the water will bring the heat way from TEC. This heat will be used as hot water in residential home.

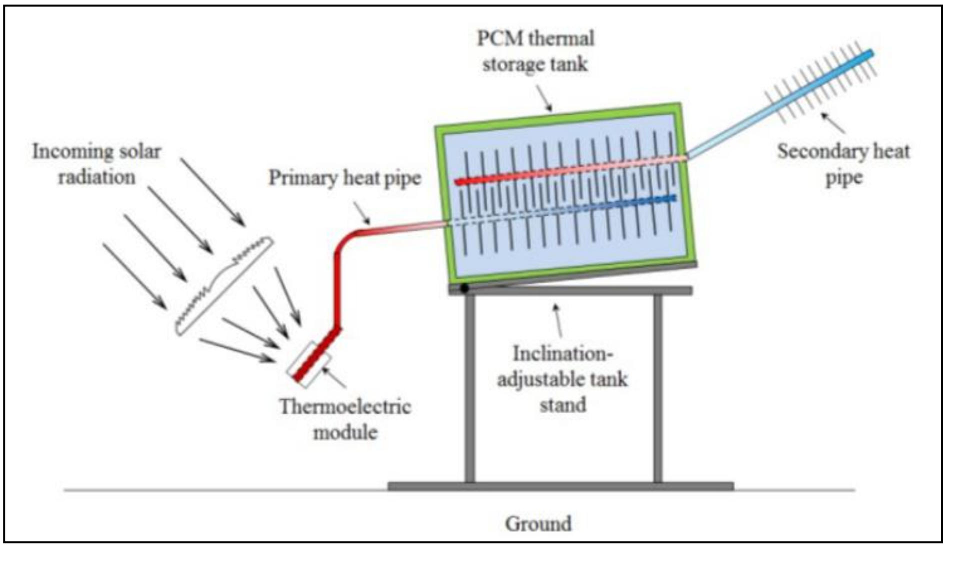

FIGURE 5. The concept diagram CTEG with PCM

Apart from that, Jalil and Sempe also investigated a suitable cooling system for thermoelectric module by using heat sink, fan and water [15]. From the experiment, heat sink do not achieve the high performance because it cannot release heat rapidly, while fan and water is suitable and good technique but fan required external electrical source to power it on. Maharaj also tested TEG module under three separate cooling arrangements which are heat-sink blower fan, heat-sink extractor fan and heat-sink blower fan with Peltier cooling combination [16]. The results show that heat-sink blower fan was the most proficient in conducting heat away from thermoelectric module cold side and produce greater temperature difference.

2.3 Thermoelectric Generator Theory

Thermoelectricity is an electrical power generate directly from the heat. The production of electrical power from heat is called Seebeck effect. This phenomenon was discovered in 1820's the by German physicist, Thomas J. Seebeck [17]. The Seebeck effect is a phenomenon where a voltage difference is produced between two materials when there is a temperature difference between two dissimilar electrical conductors or semiconductor. The higher voltage can be generated if the temperature difference is bigger. This can be calculating using equation [18];

$$V = \int_{T_1}^{T_2} \big(S_B(T) - S_A(T)\big) dT \tag{1}$$

Where T_1 and T_2 are the temperature of the two junctions and Seebeck coefficient are S_A and S_B. Thermoelectric generator produced electrical power (P) with efficiency η from the converted heat (Q) as equation;

$$P = \eta Q \tag{2}$$

The efficiency of the TEG depends on the temperature difference $\Delta T = T_h - T_c$ across the module and is defined as [19] ;

$$n = \frac{\Delta T}{T_h} \times \frac{\sqrt{1+ZT} - 1}{\sqrt{1+ZT} + \frac{T_c}{T_h}} \tag{3}$$

In which ZT is the Figure of Merit of the module and is given as;

$$ZT = \frac{\alpha^2 T}{\rho \kappa} \quad \text{where;} \tag{4}$$

α = *Seebeck coefficient*

ρ = *electrical resistivity*

κ = *thermal conductivity*

T= *temperature*

Based on the equation above, higher ZT is defined in which it depends on opposite nature of heat conductivity and electrical resistance of the particular materials while in most cases, semiconductor are preferred since it produces optimum amount of ZT.

Figure 6 below shows a schematic diagram of simple thermoelectric generator operation based on Seebeck effect. Based on Figure 6, it shows that from a high temperature heat are transferred at a rate of Q_H while heat source maintains its temperature T_H at the hot junction. The heat is delivered to a low temperature sink at a rate of Q_L while maintained T_L at the cold junction. The electrical power is produced because of the heat abounded at the hot junction causes the flow of electric current in the circuit. The electrical power output W_e is the difference between Q_H and Q_L based on first law of thermodynamics (energy conservation principle) [20].

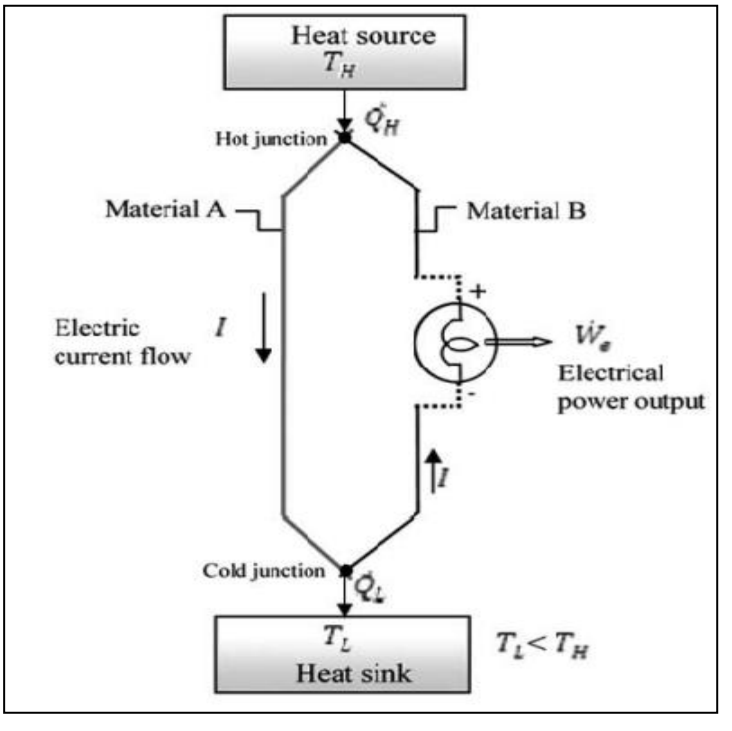

FIGURE 6. Operation of simple thermoelectric power generator

The arrangement of typical thermoelectric generator is shown in Figure 7. Based on the diagram, in order to provide mechanical integrity, thermoelectric module is composed of two ceramic plates as a foundation. It consists of pairs of p-type and n-type, where p-type is heavily doped to form excess holes and n-type which is heavily doped to from excess electron. Both charge carriers and energy carries is operated by electrons and holes. Highly conducting Silicon-germanium, SiGe or lead-telluride, PbTe is the example of semiconductor thermo element that can be used to form thermoelectric device. This thermo element must be slotted in between the ceramic plates and electrically connected in series and thermally in parallel. The highly conducting metal such as cooper strips is used to connect the junction of thermo element between hot and cold plates as shown in Figure 7 [17].

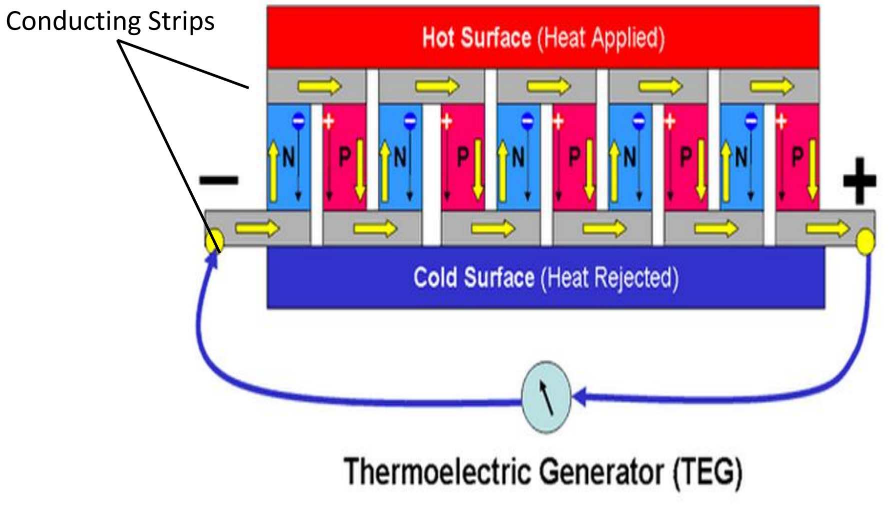

FIGURE 7. Arrangement of typical thermoelectric power generator

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 Research Methodology

In order to complete the project, a few step need to be follow as shown on the flowchart in Figure 8. Further explanation on each is described as per below:

3.1.1 Problem Definition and Component Used

Several current issues related to the extent of worldwide scope are taken into account to identify the problem statement. From the problem statement, primary objectives are listed down to verify the desire product of the project.

3.1.2 Literature Review

Further studies and research on the subject are conducted to not only important details of the project, but also to identify the status of the project through other people's research and studies any current breakthrough has been done.

3.1.3 Data Gathering and Analysis

The available data and information would include specifications of TEG and the available design and structure of domestic TEG had been done. This information is collected through the online media in order to produce a benchmark prior to the development of the proposed project. The collected data produce an idea of the expected result of the project and also provide a guideline to build up the proposed project. After that, the collected data is being analyzed in order to identify the crucial details and components required while developing the concept of design.

3.1.4 Model Development and Experimentation

The draft of the design for the system concept generation shall come first and follow by concept evaluation to identify the best concept design to carry onwards. After that, the experimentation on the configuration of TEG module shall be done in order to validate the theoretical value that had been calculated before experiment.

3.1.5 Prototype Fabrication and Assembly

After the system scheme is defined in the previous step, the fabrication of the prototype will be started. The components involved for developing the AC system for this generator will be assemble with the TEG modules.

3.1.6 Performance Testing

The prototype shall be testing through a series of experimental measures either within smaller scale or the actual condition. This process is to ensure the prototype is working well within specified requirements and achieving the expected result. Failure on this stage may require modification of the model again.

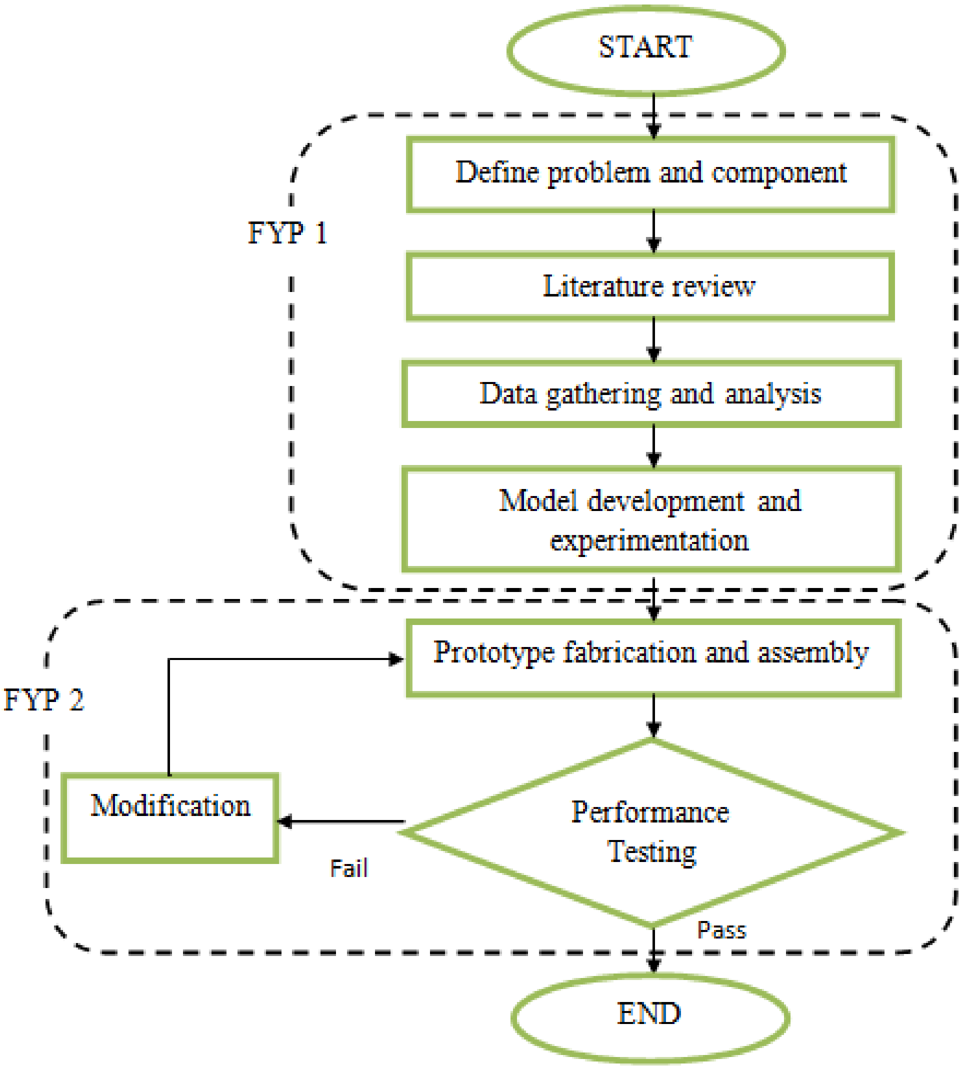

FIGURE 8. Flow chart of the project work

3.2 Project Activities

The activities for designing the proposed project are comprises into two phases as shown in Figure 9 and Figure 10. The first phase of the project would mainly involve with research and studies on related topic and the second phase would incline towards designing the prototype.

3.2.1 Phase 1

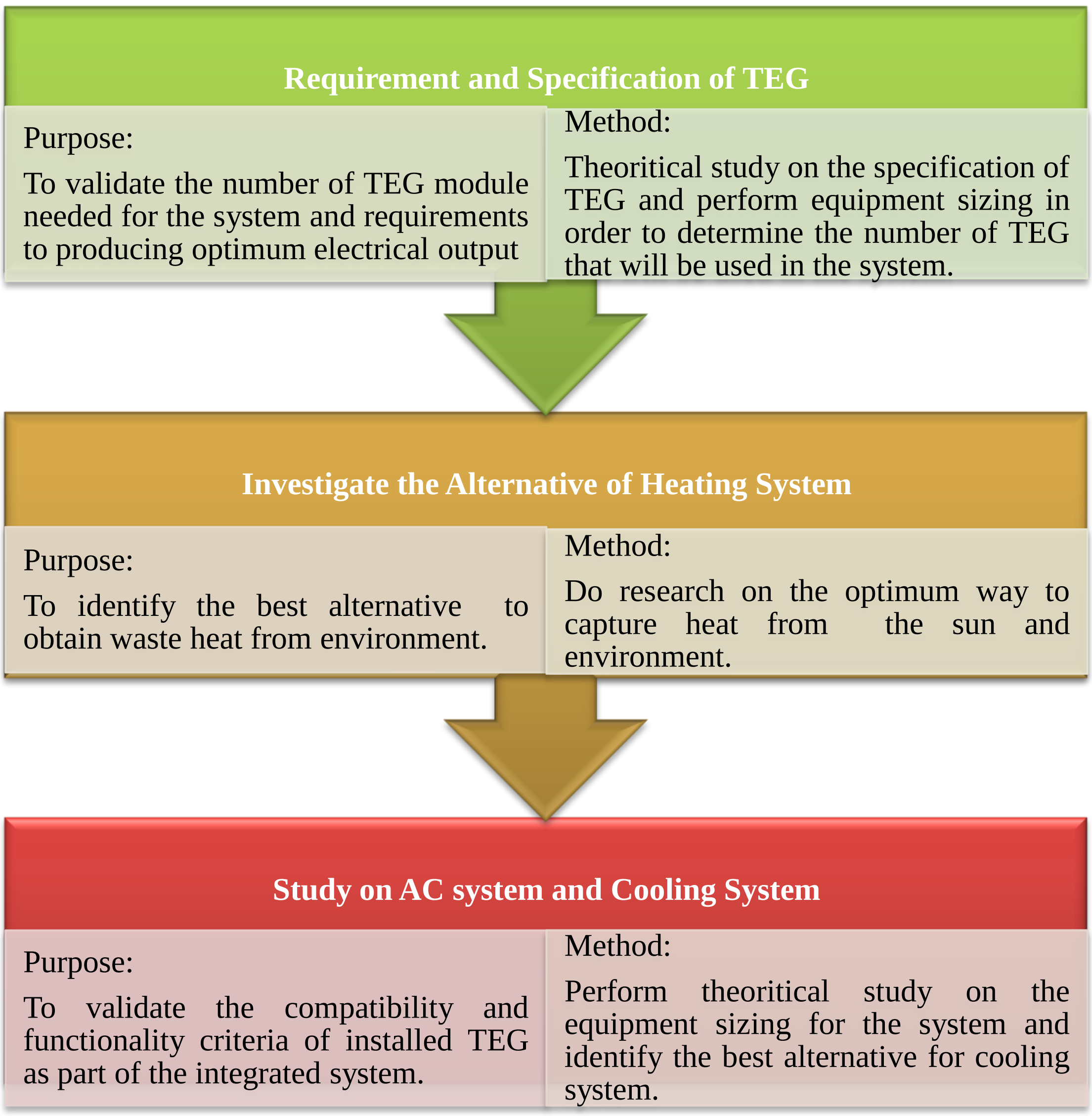

FIGURE 9. Phase 1

3.2.2 Phase 2

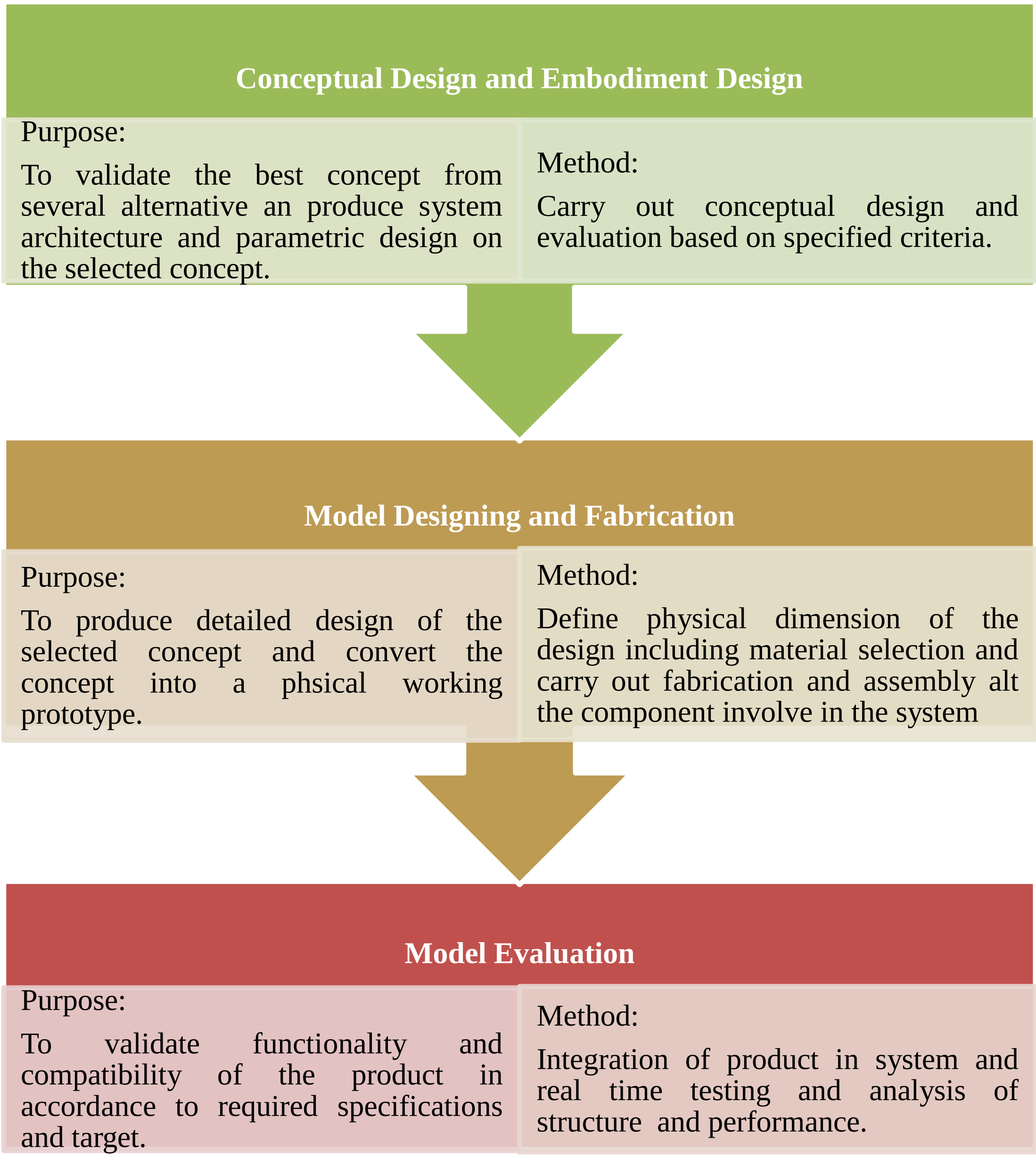

FIGURE 10. Phase 2

3.3 Project Management

3.3.1 Study Plan

Figure 11 show the activities of this project that has been plan for FYP I and FYP II.

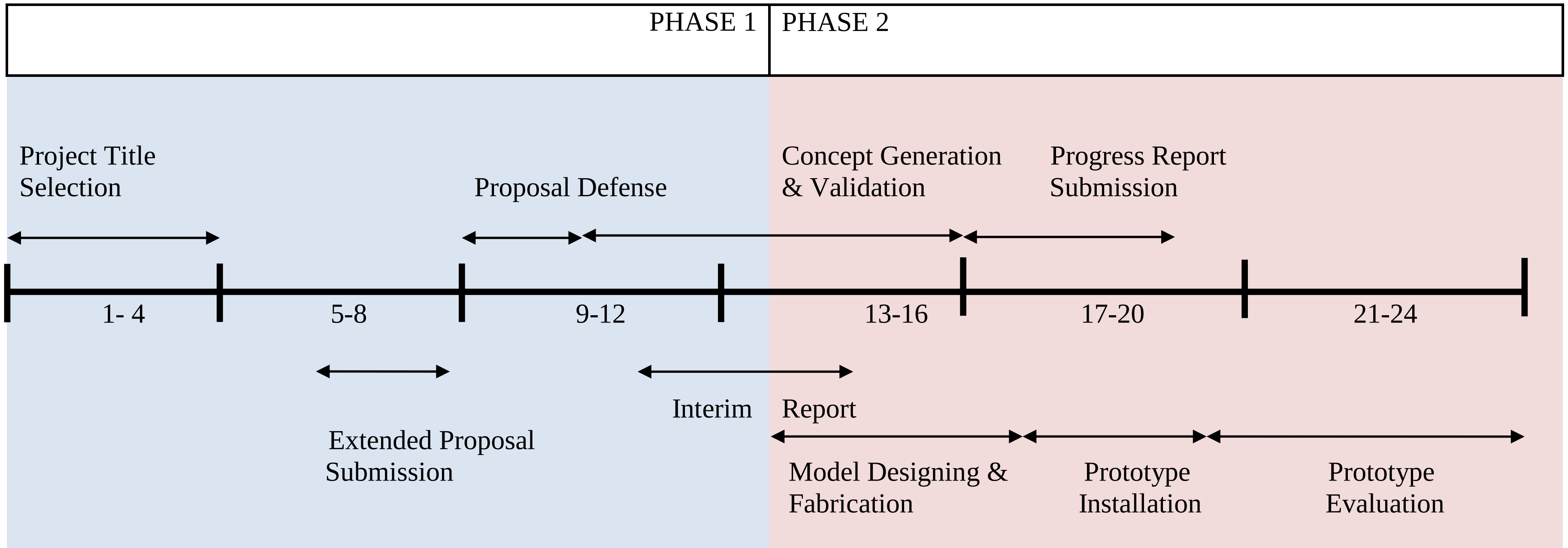

FIGURE 11. Project Activities

3.3.1 Gantt Chart and Key Milestone

TABLE 1. Gantt Chart and Key Milestone

Activities	FYP 1													FYP 2														
	Week No.																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Selection of Project Topic																												
Preliminary Research Work																												
Submission of Extended Proposal							❖																					
Proposal Defense																												
Concept Generation, Experimentation and Validation																												
Submission of Interim Report														❖														
Project Work – i. Model designing & fabrication ii. Testing and data gathering																												
Submission of Progress Report																					❖							
Project Work – Prototype installation and evaluation																												
Pre-SEDEX																								❖				
Submission of Draft Final Report																									❖			
Submission of Dissertation & Technical Paper																												❖
Viva																												❖

❖ Key Milestone Process

3.4 Tools and Equipments Required

3.4.1 Thermoelectric Module

The first step in designing TEG system is to find out the total power and energy consumption of all loads that need to be supplied by the TEG module as follows:

i. Calculate total watt-hours per day for each appliance used.

   Add the Watt-hours needed for all appliances together to get the total Watt-hours per day which must delivered by the module.
   Total appliances use = (25 W x 2 hours)
   = 50Wh/day

ii. Calculate the amount of power need to produce by TEG module.

   If the TEG module received heat source for 5 hour per day, so the TEG modules should produce:
   50 Watt hours / 5 hours heat source = 10 Watt TEG module

iii. Determine the number of TEG module.

   Since we will use voltage booster, the voltage requirement from TEG is about 3 V, 1 ampere. The estimated temperature received from the hot side of TEG is 100°C and cold side 30°C. The specification of the TEG module is shown in Table 2. To begin the design process we will review the system parameters and make some preliminary calculations. From the calculation, the number of TEG required is about 6 units in order to produce approximately 10 Watt of power when connected with voltage booster.

TABLE 2. Specification of TEG Module

Cold Side Temperature (°C)	30°C	
Hot Side Temperature (°C)	100°C	200°C
V (V)	3.22	8.54
V_{Load} (V)	1.80	4.27
I_{Load} (A)	1.01	2

R_{in} (Ω)	1.80	2.1
R_{Load} (Ω)	1.80	2.1
W_{Load} (W)	1.80	8.5

3.4.2 Voltage Booster

The voltage booster circuit is constructed using LT1073 which is versatile micro power DC/DC converter that can easily be configure as a buck or boost converter. In this project, it is basically to step up 1 V to 12 V output. The schematic design of the voltage booster circuit used in this project is shown in Figure 12.

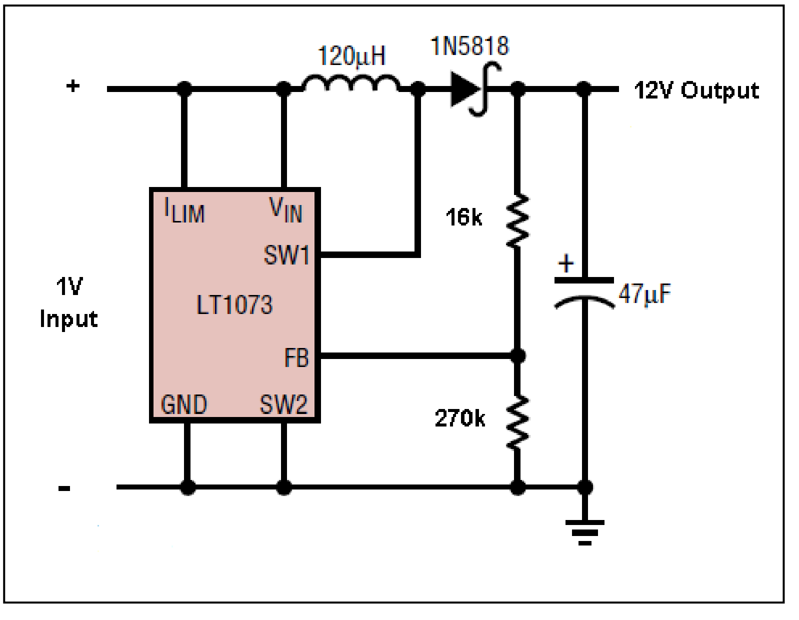

FIGURE 12. Voltage Booster Circuit

3.4.3 Battery

It is recommended for using a deep cycle battery in TEG system. Deep cycle battery is specifically designed for to be discharged to low energy level and cycle charged or rapid recharged and discharged day after day for years. In order to operate the appliances at night and cloudy days, the battery should be large enough to store sufficient energy.

Total appliances use = (25W x 2)

Nominal voltage = 12 V

Day of autonomy = 2 days

Depth of discharge = 0.6

Battery loss = 0.85

$$\text{Battery capacity} = \frac{25\ \text{W} \times 2}{(12 \times 0.6 \times 0.85)} \times 2$$

Total Ampere-hours required 16.34 Ah.

Thus, the battery should be rated 12 V 17 Ah for 2 days autonomy.

3.4.4 Charge controller

The charge controller is typically rated against voltage and amperage capacities. Choose the charge controller to match the voltage of TEG modules and batteries, and then identify which type of charge controller is suitable for the application. Ensure that charge controller has enough capacity to handle the current from TEG modules. To figure what size charge controller is needed, take the TEG wattage with normal voltage of battery.

I = 10/12 = 0.83

Takes the larger, in this case can use a 10 A charge controller.

3.4.2 Inverter

An inverter is used in the system where AC power output is needed. The input rating of the inverter should never be lower than the total watt of appliances. For stand-alone system, the inverter must be large enough to handle the total amount of Watts that will be using at one type. The inverter size should be 25-30% bigger than total Watts of appliances. Besides, the inverter also must have the same nominal voltage as the battery.

Total Watt of the appliances = 25W

For safety, the inverter should considered 25-30% bigger size

Thus, the inverter size should be about 40 W or above.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Full System Flow Diagram

In this project, the system consists of output from TEG module, charge controller, rechargeable battery and AC to DC Inverter as shown in Figure 13. The electrical power will be harvested from the heat came from solar radiation or wasted heat from the stove. The heat will be supplied to the hot side of TEG while at the cold side radiator will be used as a cooling system. Since the output voltage from TEG is small (< 3V), voltage booster is used in order to step-up the voltage to 12V. Charge controller is used to control the voltage so that it will not damage the battery.

The electrical current will be stored in battery and it is connected with DC to AC inverter in order to power up the electrical appliances such as fan or lamp. The target output from TEG modules is 10 watt and if it received 5 hours per day of heat source, then it would have generated 50 watt-hours of energy. If electrical appliance that draws 25 watts is used, then we could power about 2 hours with the energy that the TEG modules collected that day. We have the ability to store over 90 watts of energy since this project involves a battery.

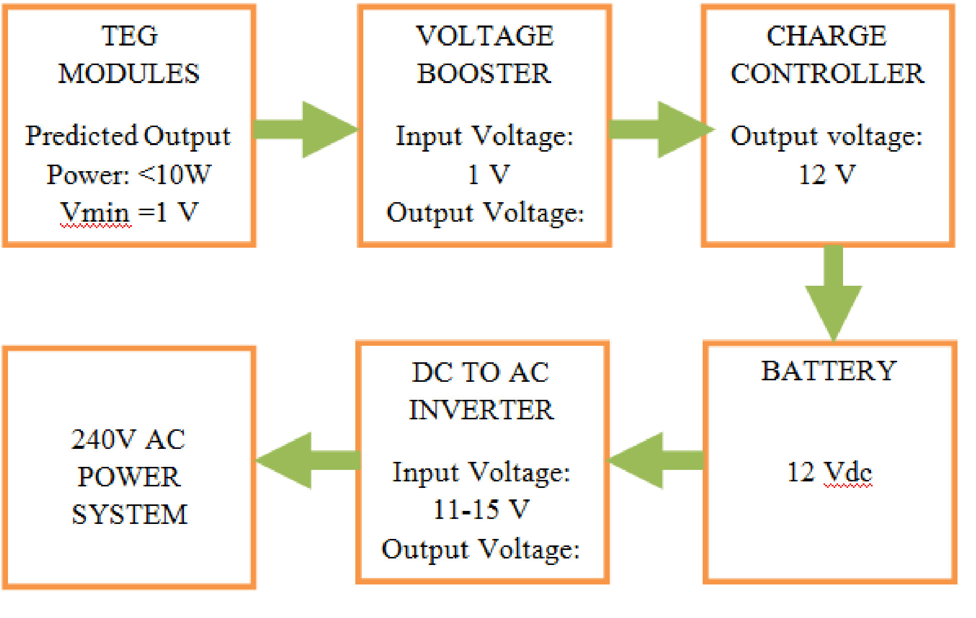

FIGURE 13. Full System Flow Diagram

4.2. Power Generation Design

The conceptual design of TEG power generation part including the function of its components is shown in Figure 14 and Table 3. For power generation part, it consists of 6 TEG modules, aluminum plate for optimum heat absorption and water block as a cooler. Water block will be connected with radiator in order to eliminate the heat from TEG

The developed TEG is design in such a way that it could absorb heat effectively from the heat source. In general, this power generation part will be connected to cooling system and power optimization. The cooling system consists of radiator and reservoir while power management made up of voltage booster, charge controller, battery and inverter.

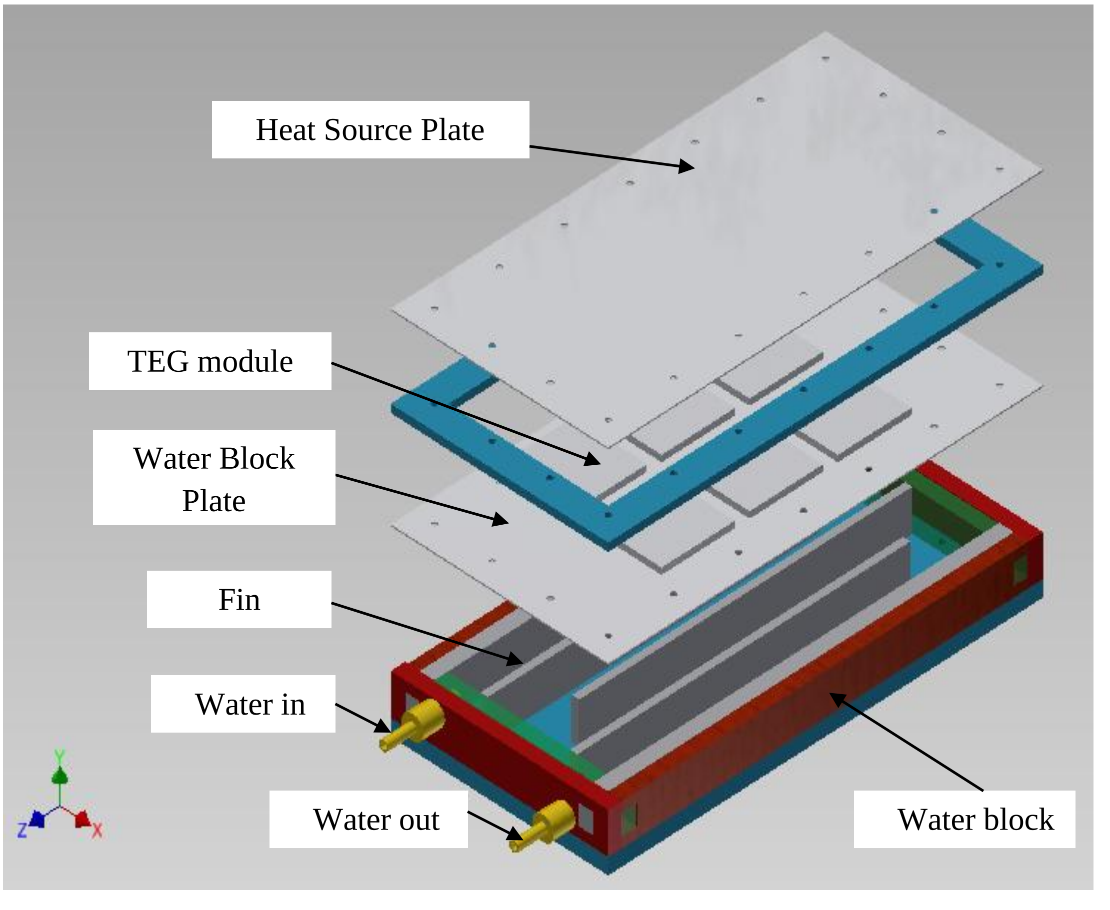

FIGURE 14. TEG Power Generation Part

TABLE 3. Components of the developed TEG

No.	TEG Part Design	Function	Material	Description
1.	Heat Source Plate	Capture heat from solar radiation and other wasted heat source.	Aluminium	Design with flat surface to make easy to install at any place.
2.	TEG Module	Allow flow of heat across the module to produce electricity.	Non Specified	6 TEG modules are connected in parallel and placed in between two aluminum plate.
3.	Water Block Plate	Removes heat from TEG modules to the cooling medium.	Aluminium	Made up from aluminium to increase heat transfer and encourage flow of heat across the TEG modules.
4.	Water Block Container	Contains and allows flow of cooling medium to remove heat from water block plate.	Perspex	Water block container channels the flow of cooling medium from reservoir.

4.3 Voltage Booster 1 Vdc to 12 Vdc

The experiment has been conducted for voltage booster of 12 Vdc. In this project, an adjustable DC/DC converter LT1073 (Refer Appendix I) is used in order to step-up voltage 1 Vdc to 12 Vdc. The output and circuit connection is shown in Figure 15.

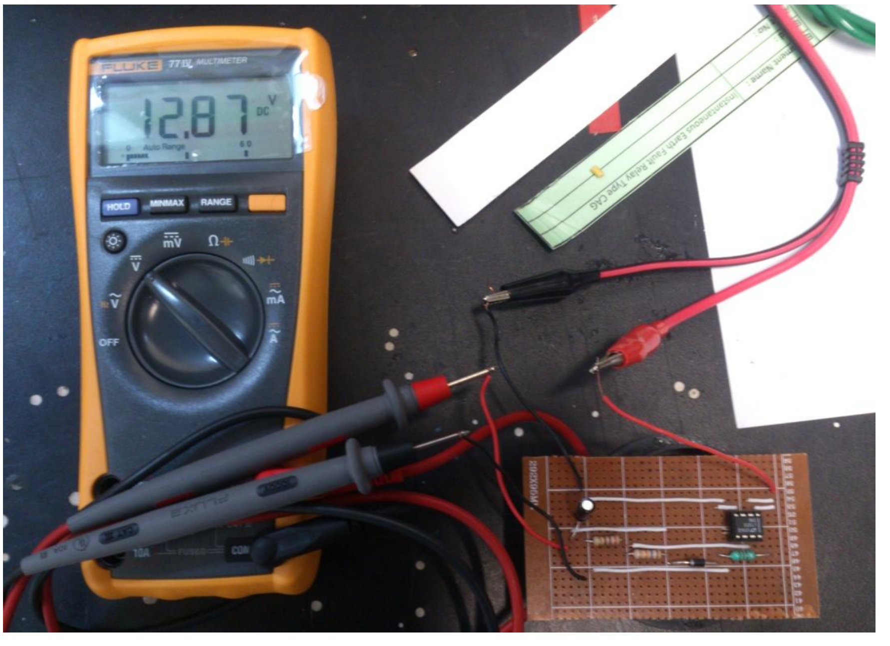

FIGURE 15. Voltage Booster (1V -12V)

The components shown in Figure 15 have been chosen following the criteria for circuit boosting theory.

- Inductor: Axial-lead units 120 uH with saturation current ratings in the range of 300mA to 1A.
- Output capacitor: Aluminum electrolytic capacitor of 47 uF is used as output capacitor in order to ensure a constant output voltage.
- Diode: 1N5818 Schottky diode is selected for LT1073 circuit (Refer Appendix II).
- Resistor: The output of the circuit is depending on two resistors which is R1 and R2. The fix value of resistors chosen is 16.3 kΩ and 270 kΩ in order to get 12 Vdc output.

4.4 Experiment on TEG Power Generation Part using Direct Heat Source

4.4.1 Open Circuit Test for Thermoelectric Generator

This experiment is conducted to measure the performance of the TEG by applying direct heat source at the hot side and running tap water as the cooling component. The experiment set up is shown in Figure 16. The aim of this experiment is to measure the maximum power produced through an extent of temperature difference. The result of the experiment is as Table 4 below.

TABLE 4. Experimental result on TEG

T_H [°C]	T_C [°C]	ΔT [°C]	Output Voltage (V)	Current (mA)
40	22	18	0.63	96.5
50	22	28	1.24	112.1
60	22	38	1.94	125.2
70	22	48	2.82	130.0
80	22	58	3.19	155.5
90	22	68	3.37	172.3
100	22	78	3.50	183.0

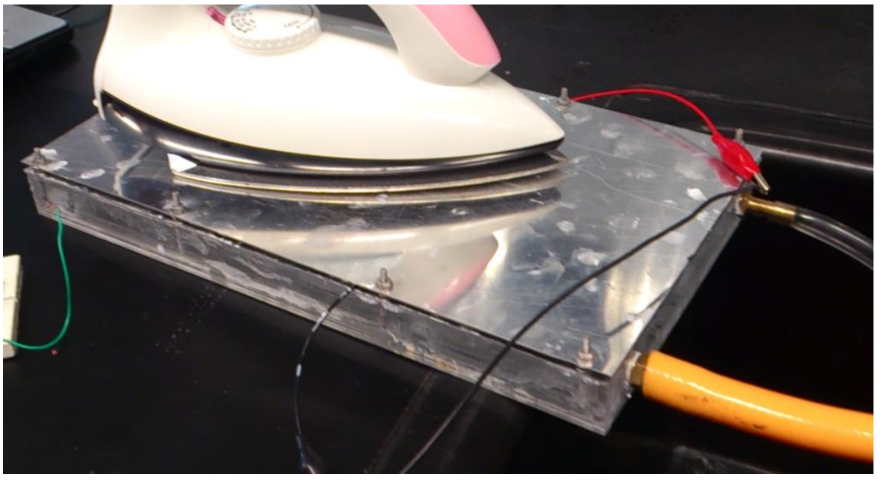

FIGURE 16. TEG's setup for direct heat source and cooling

The expected temperature achieved from the solar house is 60 °C and from the result it shows that the TEG can produce voltage around 1.94 V with current around 40 mA.

Thus, in order to charge the 12 V battery, a voltage booster is used to boost the voltage from 1 V to 12 V.

4.4.2 *Experimental Test using TEG and Voltage Booster*

The experiment is conducted by connecting the output from TEG to voltage booster in order to step-up the low voltage from TEG to 12 Vdc. The output voltage of system is shown in Figure 18.

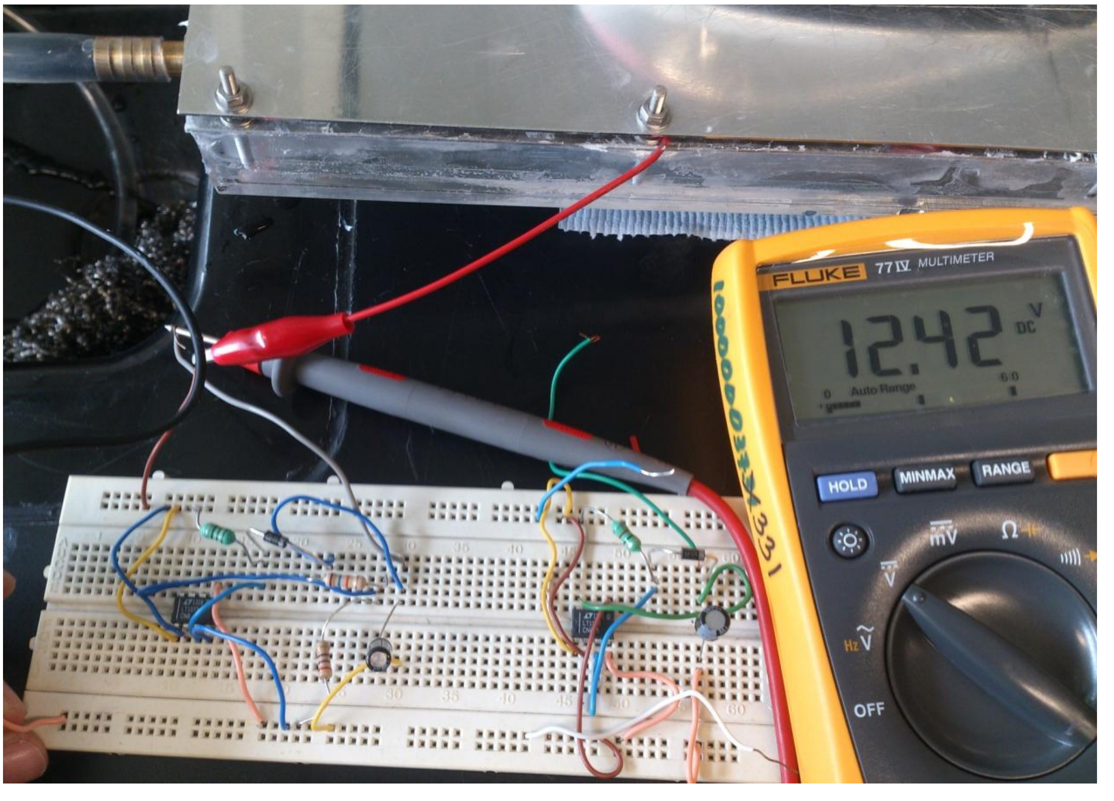

FIGURE 17. Output voltage from TEG connected to Voltage Booster

The experiment is conducted using constant temperature which is 60 °C. From the result it shows that the voltage booster can be used to step up the voltage from TEG.

4.4.3 *Experimental Test using TEG, Voltage Booster, Charge Controller and Battery*

For this experiment, TEG is tested by applying direct heat source at the hot side. For the cooling part, water from the reservoir is channeled to the water block using DC pump and water that flowing out is cooled by the radiator. The testing is set up is shown in Figure 19.

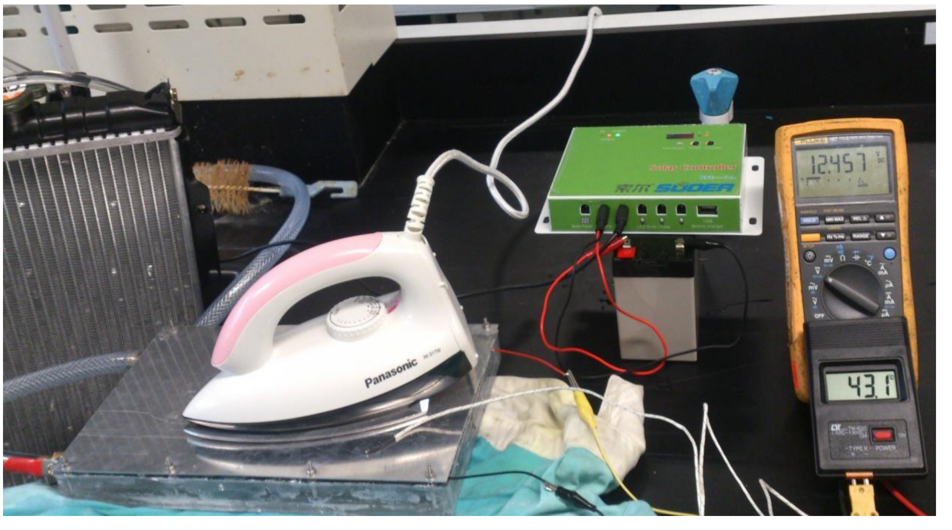

FIGURE 18. TEG test using radiator as cooling system.

The output from TEG is connected to voltage booster and produces 12.46 Vdc and is able to charge the battery using charge controller with charging current 0.7A. Figure 20 shows the output from voltage booster and charge controller.

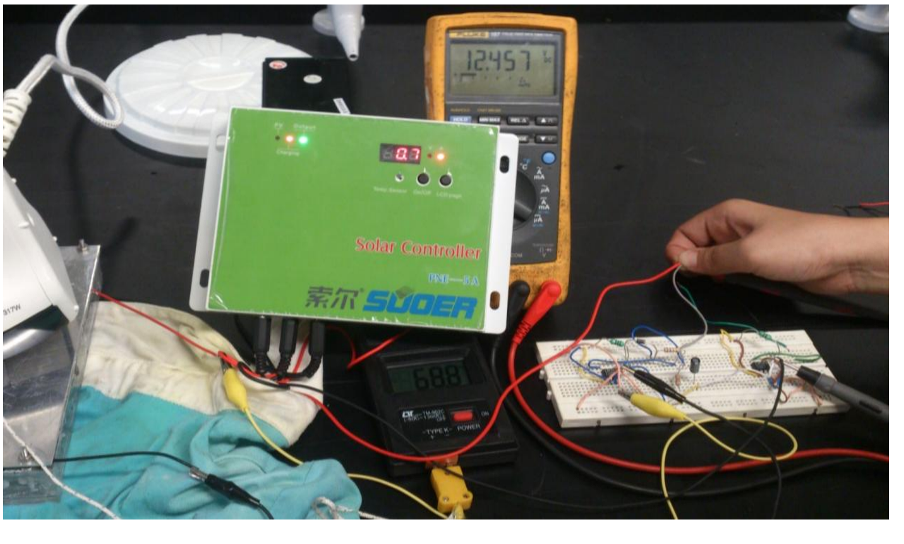

FIGURE 19. Output from voltage booster and charge controller

4.5 Heat Collector House Design

The design of the house for the outdoor application where the heat source will be obtained from solar radiation and surrounding is shown in Figure 21. TEG power generation part will be place at the roof of the house in order to get optimum solar heat reflux.

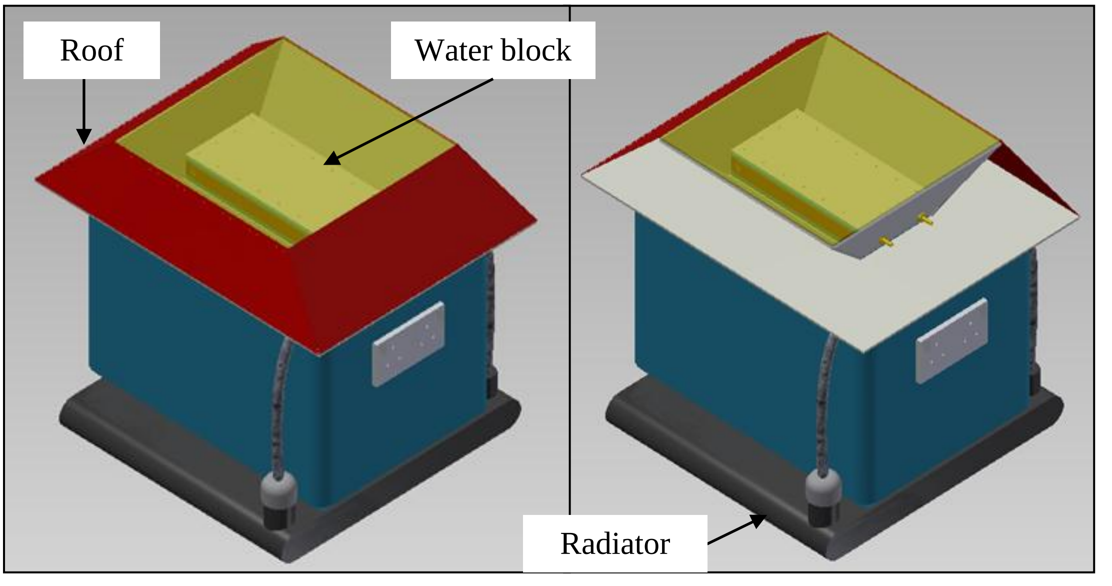

FIGURE 20. House Design

4.6 Experiment on Heat Collector House without Cooling System

Experiment has been done on the heat collector house without activate the cooling system. The aim of this experiment is to investigate the highest temperature obtain form heat collector based on the proposed design. Figure 22 shows the placement of TEG inside the house.

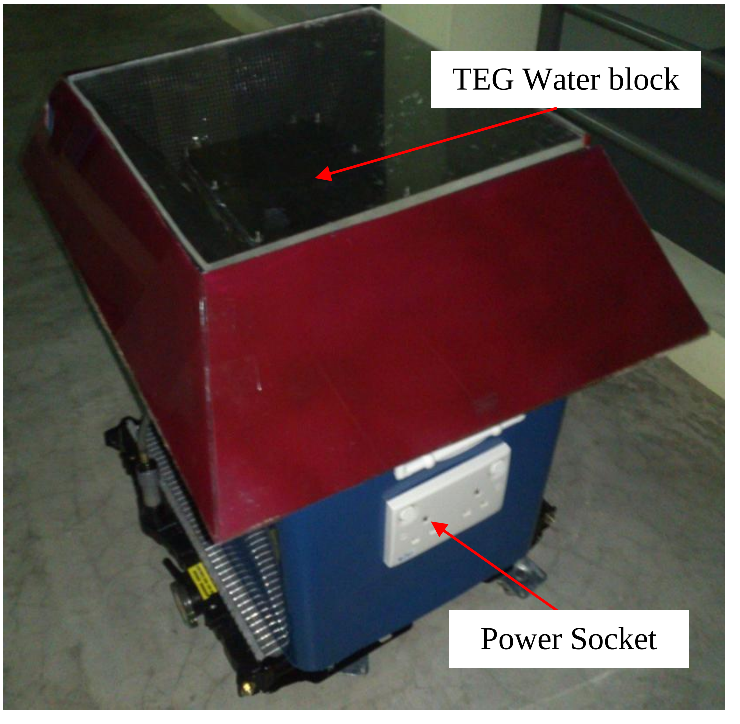

FIGURE 21. Experiment with heat collector house

Figure 23 and Figure 24 shows the result acquired from the experiment. It shows that the highest temperature obtain is 87.5 °C. The voltage and current decrease proportionally with time because the temperature difference is decrease since we not using cooling system at the cold side.

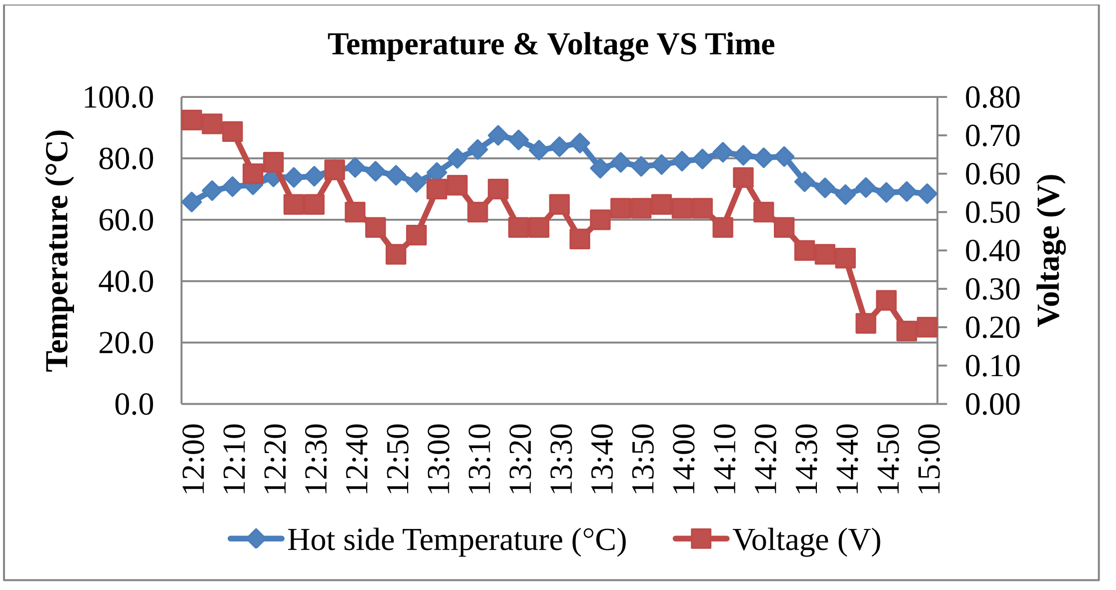

FIGURE 22. Graph of Temperature & Voltage VS Time

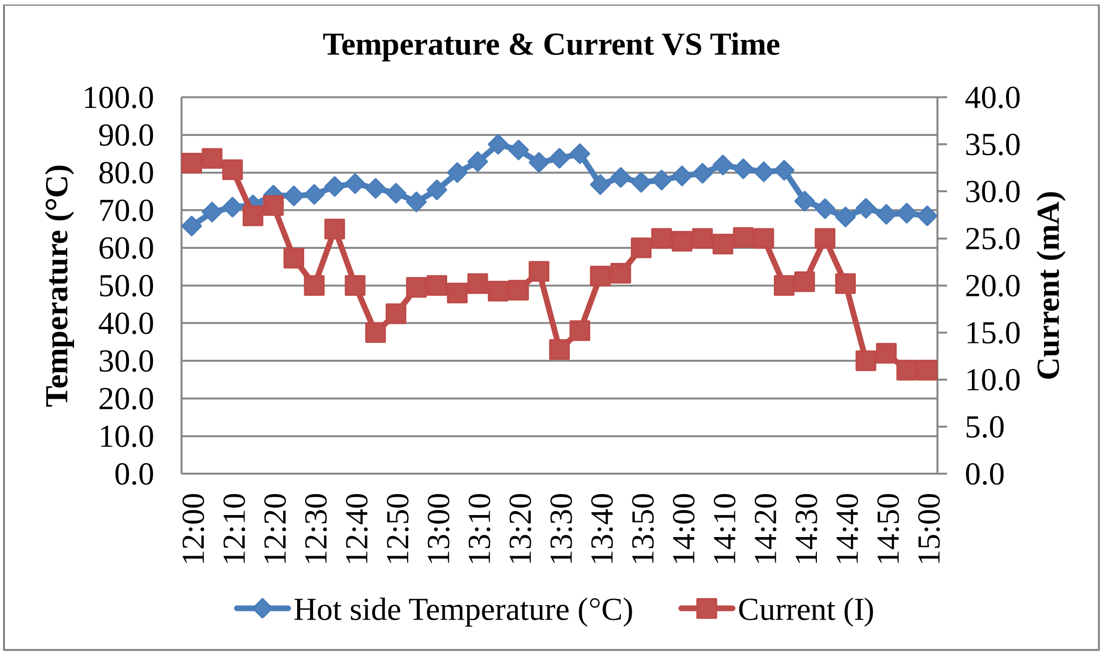

FIGURE 23. Graph of Temperature & Current VS Time

4.7 Experiment on Heat Collector House with Cooling System

Experiment has been done on the heat collector house using cooling system. The aim of this experiment is to investigate the highest output power when the heat source is from solar radiation. Figure 26 and Figure 25 shows the result acquired from the experiment. It shows that the highest temperature difference which is 38.3°C, the output voltage of TEG is 1.64 V with current 86.5mA.

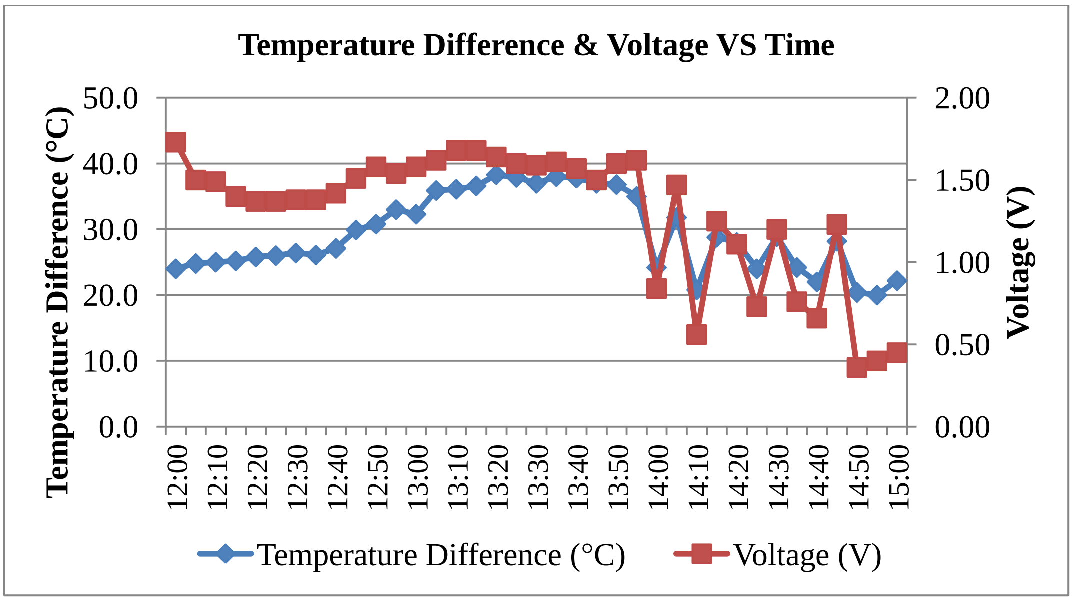

FIGURE 24. Graph of Temperature Difference & Voltage VS Time

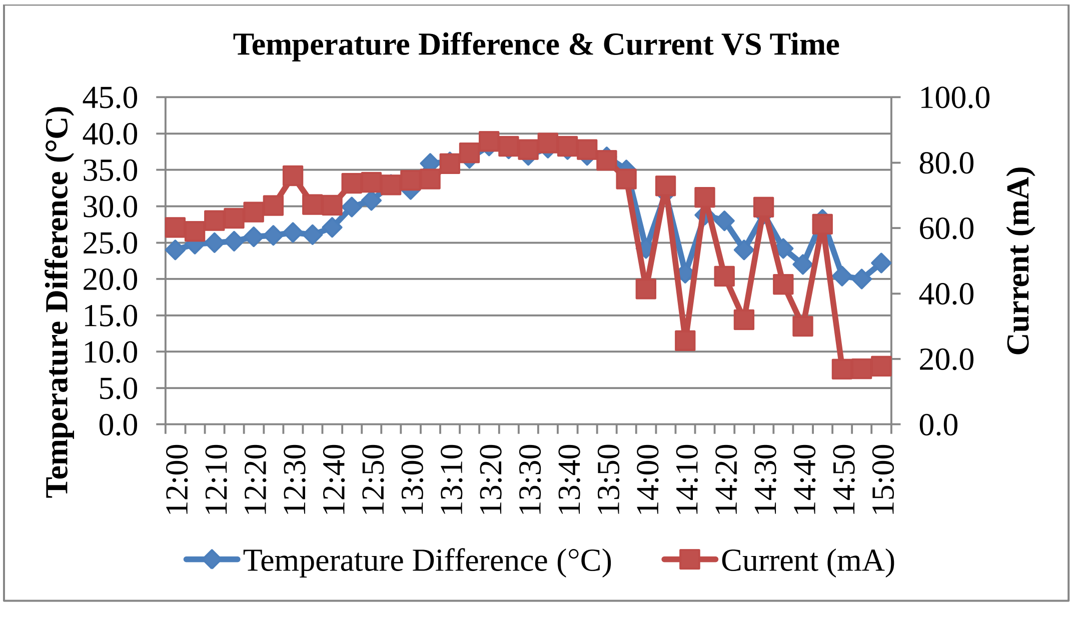

FIGURE 25. Graph of Temperature Difference & Current VS Time

4.8 Full System Electrical Connection

The electrical output of TEG is connected with voltage booster in order to charge 12 V battery. Charge controller will monitor and regulates the voltage from TEG to ensure consistence power supply to charge the battery as not pose any risk of overload. The power stored in battery will be used as a power source for domestic application. The connection from charge controller is done by extending the output from battery to inverter in order to convert DC to AC power. The power for cooling system also connected with the charge controller in order to power the water pump. Figure 27 shows the electrical wiring of TEG output.

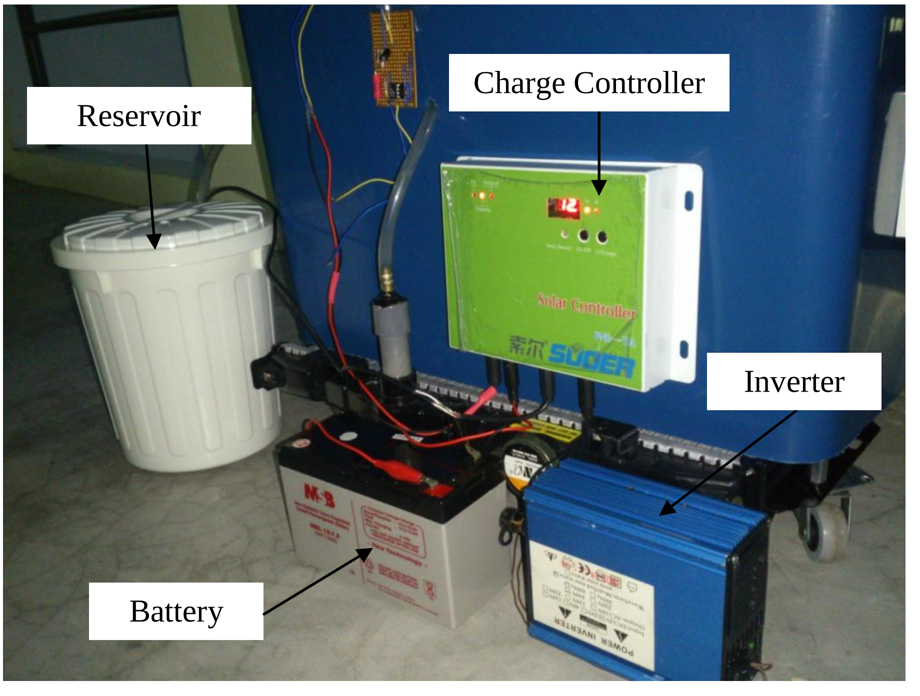

FIGURE 26. Connection of TEG output

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Development of a TEG for domestic application requires various research and studies mainly on the thermoelectric generator module as well as obtaining the effective source of heat from environment and cooling system. From the research, the author has better understanding on the theory and working principle of TEG including Seebeck effect. Research on this topic and experimental studies had been done on this project to acquire two crucial data. The first one would be the temperature range from the solar radiation and second is to know the best configuration of TEG in order to produce the optimum power.

These two critical components provide necessary information to further building a design for the prototype. The design however should not only comply with the requirements or maximum potential of the device, but also in terms of ease in fabrication and material acquisition. After designing the prototype for this generator, the investigation on the performance of TEG in different source of heat energy must be carry on for evaluation purpose. Experimental studies had been conducted on the TEG power generation part where it has been tested on outdoor in order to obtain heat from solar radiation. A special heat collector house was build for this experimental purpose. The two crucial data which is the temperature range obtained from the heat collector house and the output power from TEG has been analyzed.

By the above, the project has achieved its objective and manages to validate the concept of waste energy recovery by capturing heat energy from surrounding and produce electrical power output. The result is hoped to bring an impact towards domestic power saving through waste energy recovery system. In addition, it would also open doors to great opportunities and achievement in the technology which would provide more values and better performance.

5.2 Recommendations

Developed in less than six months, the TEG is not finite in performance and several modifications are identified which are seen as a possible improvements to increase the power output in particular.

5.2.1 Use Fresnel Lens for Heat Collector

It is recommended to use Fresnel lens or solar concentrator to get optimum heat energy from solar radiation. This is because the larger the temperature difference on the TEG module, the higher output power will be produced.

FIGURE 27. Fresnel Lens

5.2.2 Increase the number of TEG module

The developed prototype consist only six TEG modules which responsible for the energy conversion. It is recommended to increase the number of TEG modules in order to increase the efficiency for charging the battery.

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APPENDICES

APPENDIX I

LINEAR TECHNOLOGY

LT1073

Micropower DC/DC Converter Adjustable and Fixed 5V, 12V

FEATURES

- No Design Required
- Operates at Supply Voltages from 1V to 30V
- Consumes Only 95μA Supply Current
- Works in Step-Up or Step-Down Mode
- Only Three External Off-the-Shelf Components Required
- Low-Battery Detector Comparator On-Chip
- User-Adjustable Current Limit
- Internal 1A Power Switch
- Fixed or Adjustable Output Voltage Versions
- Space-Saving 8-Pin PDIP or SO-8 Package

APPLICATIONS

- Pagers
- Cameras
- Single-Cell to 5V Converters
- Battery Backup Supplies
- Laptop and Palmtop Computers
- Cellular Telephones
- Portable Instruments
- 4mA to 20mA Loop Powered Instruments
- Hand-Held Inventory Computers
- Battery-Powered α, β, and γ Particle Detectors

DESCRIPTION

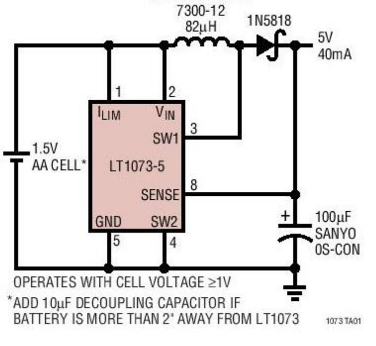
The LT®1073 is a versatile micropower DC/DC converter. The device requires only three external components to deliver a fixed output of 5V or 12V. The very low minimum supply voltage of 1V allows the use of the LT1073 in applications where the primary power source is a single cell. An on-chip auxiliary gain block can function as a low-battery detector or linear post-regulator.

Average current drain of the LT1073-5 used as shown in the Typical Application circuit below is just 135μA unloaded, making it ideal for applications where long battery life is important. The circuit shown can deliver 5V at 40mA from an input as low as 1.25V and 5V at 10mA from a 1V input.

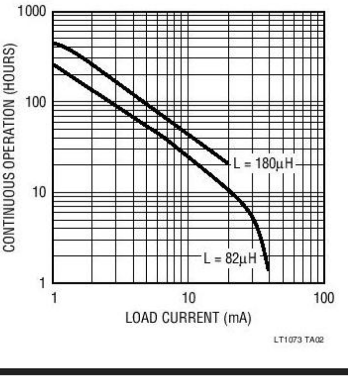
The device can easily be configured as a step-up or step-down converter, although for most step-down applications or input sources greater than 3V, the LT1173 is recommended. Switch current limiting is user-adjustable by adding a single external resistor. Unique reverse-battery protection circuitry limits reverse current to safe, nondestructive levels at reverse supply voltages up to 1.6V.

TYPICAL APPLICATION

Single-Cell to 5V Converter



Single Alkaline "AA" Cell Operating Hours vs DC Load Current



ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. V_{IN} = 1.5V unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
I_{REV}	Reverse Battery Current	(Note 5)			750		mA
I_{LIM}	Current Limit	220Ω Between I_{LIM} and V_{IN}			400		mA
	Current Limit Temperature Coefficient				–0.3		%/°C
I_{LEAK}	Switch OFF Leakage Current	Measured at SW1 Pin			1	10	µA
V_{SW2}	Maximum Excursion Below GND	I_{SW1} ≤ 10µA, Switch Off			–400	–350	mV

Note 1: Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.

Note 2: This specification guarantees that both the high and low trip point of the comparator fall within the 202mV to 222mV range.

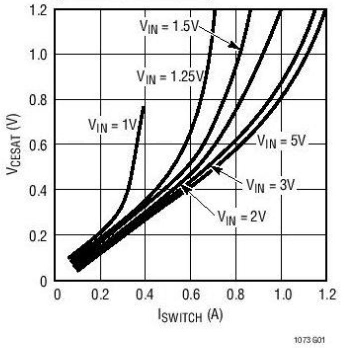
Note 3: This specification guarantees that the output voltage of the fixed versions will always fall within the specified range. The waveform at the SENSE pin will exhibit a sawtooth shape due to the comparator hysteresis.

Note 4: 100k resistor connected between a 5V source and the AO pin.

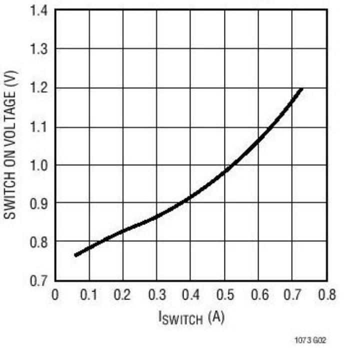
Note 5: The LT1073 is guaranteed to withstand continuous application of 1.6V applied to the GND and SW2 pins while V_{IN}, I_{LIM} and SW1 pins are grounded.

TYPICAL PERFORMANCE CHARACTERISTICS

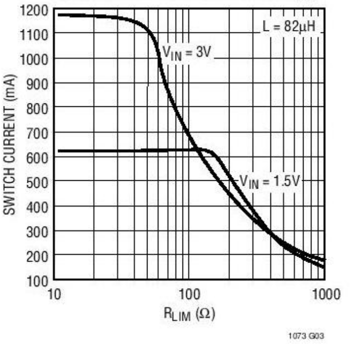
Saturation Voltage Step-Up Mode (SW2 Pin Grounded)



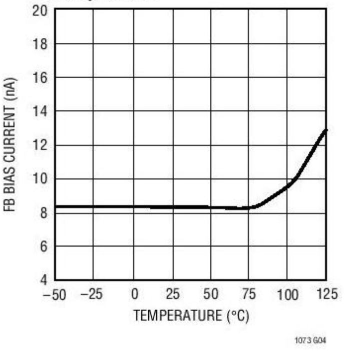
Switch ON Voltage Step-Down Mode (SW1 Pin Connected to V_{IN})



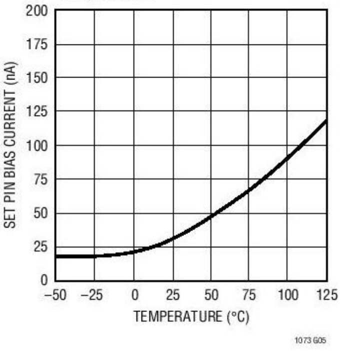
Maximum Switch Current vs R_{LIM}



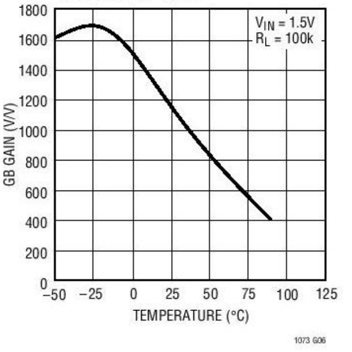
FB Pin Bias Current vs Temperature



SET Pin Bias Current vs Temperature



"Gain Block" Gain

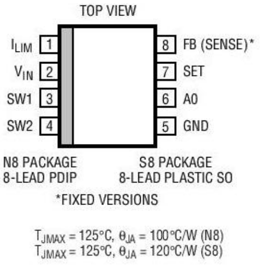


ABSOLUTE MAXIMUM RATINGS

(Note 1)

Supply Voltage, Step-Up Mode 15V
Supply Voltage, Step-Down Mode 36V
SW1 Pin Voltage 50V
SW2 Pin Voltage .... -0.4 to V_{IN}
Feedback Pin Voltage (LT1073) 5V
Switch Current 1.5A
Maximum Power Dissipation 500mW
Operating Temperature Range .... 0°C to 70°C
Storage Temperature Range .... -65°C to 150°C
Lead Temperature (Soldering, 10 sec).................. 300°C

PACKAGE/ORDER INFORMATION



ORDER PART NUMBER
LT1073CN8
LT1073CN8-5
LT1073CN8-12
LT1073CS8
LT1073CS8-5
LT1073CS8-12
S8 PART MARKING
1073
10735
107312

Consult factory for parts specified with wider operating temperature ranges.

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. V_{IN} = 1.5V unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS			MIN	TYP	MAX	UNITS
I_Q	Quiescent Current	Switch Off		●		95	130	µA
I_Q	Quiescent Current, Step-Up Mode Configuration	No Load	LT1073-5 LT1073-12			135 250		µA µA
V_{IN}	Input Voltage	Step-Up Mode		●	1.15 1.0		12.6 12.6	V V
		Step-Down Mode		●			30	V
	Comparator Trip Point Voltage	LT1073 (Note 2)		●	202	212	222	mV
V_{OUT}	Output Sense Voltage	LT1073-5 (Note 3) LT1073-12 (Note 3)		● ●	4.75 11.4	5 12	5.25 12.6	V V
	Comparator Hysteresis	LT1073		●		5	10	mV
	Output Hysteresis	LT1073-5 LT1073-12		● ●		125 300	250 600	mV mV
f_{OSC}	Oscillator Frequency			●	15	19	23	kHz
DC	Duty Cycle	Full Load ($V_{FB} = V_{REF}$)		●	65	72	80	%
t_{ON}	Switch ON Time			●	30	38	50	µs
I_{FB}	Feedback Pin Bias Current	LT1073, V_{FB} = 0V		●		10	50	nA
I_{SET}	Set Pin Bias Current	$V_{SET} = V_{REF}$		●		60	120	nA
V_{AO}	AO Output Low	$I_{AO} = -100\mu A$		●		0.15	0.4	V
	Reference Line Regulation	$1V \le V_{IN} \le 1.5V$ $1.5V \le V_{IN} \le 12V$		● ●		0.35 0.05	1.0 0.1	%V %V
V_{CESAT}	Switch Saturation Voltage Set-Up Mode	V_{IN} = 1.5V, I_{SW} = 400mA		 ●		300	400 600	mV mV
		V_{IN} = 1.5V, I_{SW} = 500mA		 ●		400	550 750	mV mV
		V_{IN} = 5V, I_{SW} = 1A		 ●		700	1000 1500	mV mV
A_V	A2 Error Amp Gain	$R_L = 100k\Omega$ (Note 4)		●	400	1000		V/V

APPENDIX II

FAIRCHILD SEMICONDUCTOR®

November 2010

1N5817 - 1N5819
Schottky Barrier Rectifier

Features

- 1.0 ampere operation at T_A = 90°C with no thermal runaway.
- For use in low voltage, high frequency inverters free wheeling, and polarity protection applications.

DO-41 plastic case
COLOR BAND DENOTES CATHODE

Absolute Maximum Ratings* T_A = 25°C unless otherwise noted

Symbol	Parameter	Value			Units
		1N5817	1N5818	1N5819	
V_{RRM}	Maximum Repetitive Reverse Voltage	20	30	40	V
$I_{F(AV)}$	Average Rectified Forward Current .375" lead length @ T_A = 90°C	1.0			A
I_{FSM}	Non-repetitive Peak Surge Current 8.3 ms Single Half-Sine Wave	25			A
T_J, T_{STG}	Operating Junction and Storage Temperature	-65 to +125			°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

Thermal Characteristics

Symbol	Parameter	Value	Units
P_D	Power Dissipation	1.25	W
$R_{\theta JA}$	Maximum Thermal Resistance, Junction to Ambient	100	°C/W
$R_{\theta JC}$	Maximum Thermal Resistance, Junction to Case	45	°C/W

* Mounted on Cu-pad Size 5mm x 5mm on PCB

Electrical Characteristics (per diode)

Symbol	Parameter		Value			Units
			1N5817	1N5818	1N5819	
V_F	Forward Voltage	@ 1.0 A @ 3.0 A	450 750	550 875	600 900	mV mV
I_R	Reverse Current @ rated V_R	T_C = 25 °C T_C = 100 °C	0.5 10			mA mA
C_T	Total Capacitance V_R = 4.0 V, f = 1.0 MHz		110			pF

* Pulse Test: Pulse Width=300µs, Duty Cycle=2%